

Amendments to the Specification:

Please replace paragraph [002] with the following amended paragraph:

[002] This invention relates to metrology systems and methods ~~in~~ for determining features of sub-micron structural elements such as lines, contacts, trenches and the like, of ~~measure~~ measured objects such as, but not limited to, semiconductors wafers~~[,]~~ and reticles.

Please replace paragraph [003] with the following amended paragraph:

[003] Integrated circuits are very complex devices that include multiple layers. Each layer may include conductive material~~[,]~~ and isolating material, while other layers may include semi-conductive materials. These various materials are arranged in patterns, usually in accordance with the expected functionality of the integrated circuit. The patterns also reflect the manufacturing process of the integrated circuits.

Please replace paragraph [004] with the following amended paragraph:

[004] Integrated circuits are manufactured by complex multi-staged manufacturing processes. During this multi-staged process, resistive material is (i) deposited on a substrate~~[/]~~ layer, (ii) exposed by a photolithographic process, and (iii) developed to produce a pattern that defines some areas to be later etched.

Please replace paragraph [005] with the following amended paragraph:

[005] Various metrology, inspection and failure analysis techniques have evolved for inspecting integrated circuits both during the fabrication stages, between consecutive manufacturing stages, either in combination with the manufacturing process (also termed “in line” inspection techniques) or not (also termed “off line” inspection techniques). Various optical as well as charged particle beam inspection tools and review tools are known in the art, such as the VeraSEM™, Compluss™ and SEMVision™ of Applied Materials Inc. of Santa Clara, California.

Please replace paragraph [007] with the following amended paragraph:

[007] One of the goals of metrology is to determine whether the inspected objects ~~includes~~ include deviations from these critical dimensions. This inspection is usually done by charged particles ~~particle~~ beam imaging that ~~provide~~ provides the high resolution required to measure said deviations.

Please replace paragraph [009] with the following amended paragraph:

[009] Measurement of a structural element ~~line~~ line's critical dimensions using only a top view (in which the electron beam that scans the line is perpendicular to the substrate) may result in faulty results, especially when one of the sidewalls has a negative sidewall angle such that an upper end of the sidewall obscures a lower end of that sidewall.

Please replace paragraph [0010] with the following amended paragraph:

[0010] In order to address said inaccuracies, CD-SEM tools that enable electronic tilt of an electron beam were introduced. NanoSem 3D, of Applied Materials from Santa Clara, is a fully automated CD-SEM that has a column that allows electronic tilting as well as mechanical tilting of the scanning electron beam to scan the wafer surface with various tilt angles from several directions.

Please replace paragraph [0012] with the following amended paragraph:

[0012] Multiple measurements have some disadvantages. First, they reduce the throughput of the inspection system, especially when the measurement involves changing the tilt of ~~the~~ scanning electron beam. Such a change may require a de-Gauss stage, as well as an electron beam stabilization stage. A further disadvantage of multiple measurements results from degradation (for example shrinkage and carbonization) of the measured structural element, as well as unwanted charging of the measured structural element.

Please replace paragraph [0013] with the following amended paragraph:

[0013] Due to various reasons, such as process variations, measurement inaccuracies and the like, the height and accordingly the measured height of structural elements varies across measured objects. In order to determine the structural height of a measured structural element, there is a need to perform at least two measurements of said structural element, at

two different tilt angles. The height of the structural element may be estimated, usually in response to multiple height measurements of structural element across the measured object. The estimation may be associated with height measurement errors, as well as estimation errors, that can affect the critical dimension measurements.

Please replace paragraph [0014] with the following amended paragraph:

[0014] The invention provides various scanning schemes that enable to selectively reduce reducing the amount of measurements required for determining cross sectional features of structural elements.

Please replace paragraph [0017] with the following amended paragraph:

[0017] The invention provides a method for determining a cross sectional feature of a measured structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse sections. The method includes a first step of scanning a portion of at least one reference structural element and a portion of the measured structural element to determine one or more relationships between the at least one reference structural element and the measured structural element. The first scanning step may be followed by additional scanning steps. According to an embodiment of the invention, at least one additional scanning step is mandatory. According to other embodiments of the invention, one or more additional scanning steps are optional, and their execution may be responsive to a fulfillment of various conditions, such as an uncertainty associated with the results of the previous scan. The uncertainty may be related to a steepness or orientation of a portion of a section of a measured structural element, to a relationship between a width of a section of the measured element and to a width of an electron beam that scans that section. The conditions may also reflect the required signal to noise ratio of the measurement, the accuracy of the measurement, and, optionally or alternatively, to the topography of the measured object.

Please replace paragraph [0018] with the following amended paragraph:

[0018] If additional scans are performed, additional relationships may be determined. Usually, the sean scans are preformed performed at different scan states.

Please replace paragraph [0019] with the following amended paragraph:

[0019] According to an aspect of the invention, one or more reference structural elements are provided. If multiple reference structural elements are provided, reference structural element as a result of an interaction with the electron they elements may be positioned on both sides of a measured structural element, but this is not necessarily so.

Please replace paragraph [0020] with the following amended paragraph:

[0020] The invention provides a system for determining a cross sectional feature of a structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a-first and a-second traverse sections, the system includes including means for directing an electron beam towards an inspected object, at least one detector that is positioned such so as to detect electrons emitted from the beam; and a processor, coupled to the at least one detector. The system is capable of performing at least one measurement, at one or more tilt states, to determine one or more relationships between one or more structural element elements and portions of a measured structural element. At least two relationship helps relationships help to determine the cross sectional feature.

Please replace paragraph [0023] with the following amended paragraph:

[0023] Figure 1b is a perspective view of an objective lens, according to another embodiment of the invention;

Please replace paragraph [0024] with the following amended paragraph:

[0024] Figure Figures 2a-2b illustrate various lines and reference structural elements;

Please replace paragraph [0025] with the following amended paragraph:

[0025] Figures 3a – 3c are schematic illustration illustrations of waveforms that represent a relatively wide positively oriented traverse section, a relatively narrow traverse section and a negative oriented traverse section;

Please replace paragraph [0026] with the following amended paragraph:

[0026] Figure 4 is a flow ~~charts~~ chart of a ~~methods~~ method for determining an edge of a structural element having a sub-micron cross section, in accordance with an embodiment of the invention; and

Please replace paragraph [0027] with the following amended paragraph:

[0027] Figures 5-9 are flow charts of methods for determining a cross sectional feature of a measured structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a-first and a-second traverse sections.

Please replace paragraph [0028] with the following amended paragraph:

[0028] A typical CD-SEM includes an electron gun, for generating an electron beam, deflection and tilt units as well as focusing lens, for enabling scanning of a specimen with an electron beam, that may be in a certain tilt condition, while reducing various aberrations and misalignments. Electrons, such as secondary electrons, ~~that are emitted~~ emitted as result of an interaction between the specimen and the electron beam are attracted to a detector that provides detection signals ~~that which are subsequently~~ processed by a processing unit. The detection signals may be used to determine various features of the specimen, as well as form images of the inspected specimen.

Please replace paragraph [0029] with the following amended paragraph:

[0029] The invention may be implemented on CD-SEMs of various architectures that may differ from each other by the ~~amount~~ number of their parts as well as the arrangement of said parts. For example the ~~amount~~ number of deflection units, as well as the exact structure of each unit may vary. The CD-SEM may include in-lens as well as ~~out-of-lens~~ out-of-lens detectors or a combination of both.

Please replace paragraph [0030] with the following amended paragraph:

[0030] A block diagram of a critical dimension scanning electron microscope (CD-SEM) 100 is shown schematically in Fig. 1a. CD-SEM 100 includes an electron gun 103 emitting an electron beam 101, which is extracted by the anode 104. The objective lens 112 focuses the electron beam on the specimen surface 105a. The beam is scanned over the specimen

using the scanning deflection unit 102. An alignment of the beam to the aperture 106 or a desired optical axis respectively can be achieved by the deflection units 108 to 111. As a
Instead of deflection unit coils, electrostatic modules in the form of charged plates or a combination of coils and electrostatic deflectors can be used.

Please replace paragraph [0031] with the following amended paragraph:

[0031] In-lens detector 16 is able to detect secondary electrons that escape from the specimen 105 at a variety of angles with relatively low energy (3 to 50 eV). Measurements of scattered or secondary corpuscles from a specimen can be conducted with detectors in the form of scintillators connected to photomultiplier tubes or the like. Since the way of measuring the signals does not influence the inventive idea in general, this is not to be understood as limiting the invention. It is noted that the CD-SEM may include, additionally or alternatively, at least one out-of-lens out-of-lens detector.

Please replace paragraph [0033] with the following amended paragraph:

[0033] The different parts of the system are connected to corresponding supply units (such as high voltage supply unit 21) that are controlled by various control units, most of them ~~are~~ omitted from the figure for simplifying the explanation. The control units may determine the current supplied to a certain part, as well as the voltage.

Please replace paragraph [0035] with the following amended paragraph:

[0035] Figure 1b is a perspective view of an objective lens 120, according to another embodiment of the invention. In figure 1b, the tilt deflection is performed below (downstream direction) of the objective lens. Objective lens differs from objective lens 102 112 by having a pole-piece arranged in a quadrupole quadrupole formation, positioned between the objective lens and specimen, for controlling the tilt condition of the electron beam. The polepieces are electrically connected to a ring and a core that bears additional coils (not shown) that are arranged ~~such so~~ as to concentrate a magnetic flux ~~at in~~ in the space between the polepieces, through which the electron beam passes.

Please replace paragraph [0037] with the following amended paragraph:

[0037] Various features of the cross section may be of interest. These feature features may include, for example[[:]], the shape of the cross section, the shape of one or more sections of the cross section, the width and/or height and/or angular orientation of the cross section sections, as well as the relationship between cross section sections. The feature can reflect typical values, as well as maximal and/or minimal values. Typically the width of the bottom of a line is of interest, but this is not necessarily so, and other features may be of interest.

Please replace paragraph [0038] with the following amended paragraph:

[0038] Figure 2a illustrates a perspective as well as a cross sectional view of line 210 and a reference structural element, such as bump 250. Line 210 has a cross section 230 that includes a top section 234-224 and two substantially opposing traverse sections 222 and 226 (that correspond to the top section 214 as well as to two sidewalls 212 and 216 of line 210) that are both positively oriented at substantially opposing angles, such that the bottom of the line is not obscured by the top section 214.

Please replace paragraph [0039] with the following amended paragraph:

[0039] Bump 250 is much smaller than line 210 and has at least one point, such as certain point 251, that is located substantially at the same plane as the lower points 233 and 237 of first and second traverse sections 232-222 and 236-226. Bump 250 is located such so as to be viewed by electron beams that are used to scan the first traverse section as well as electron beams used to scan the second traverse section. The location of bump 250, and especially the relationship between its height (which is usually much smaller than the height of line 210) and the distance between bump 250 and line 210 are calculated to allow the bump 250 to be viewed by both type types of electron beams. The distance can be responsive to the maximal tilt angle of the scanning electron beam. As a rule of thumb, the distance between bump 250 and line 210 has to be greater than $H_{max} \times \text{Tangents tangent}(A_{max})$, whereas in which H_{max} being a is the maximal height of line 210 and A_{max} being a is the maximal tilt angle of a scanning electron beam.

Please replace paragraph [0040] with the following amended paragraph:

[0040] The inventors found out that a bump can be generated relatively quickly using a charged electron beam that interacts with an object to provide a bump based upon the carbonization phenomena. For example, [[-]] the inventors generated a 0.5 micron long carbonization line in less than a minute. Very good results were achieved by generating the bump by scanning the object multiple times (such as, but not limited to 10-50 scans) with a relatively low current electron beam (such as, but not limited to 20, 50, 100pA and the like). The inventors also found that such bumps can be achieved by using various acceleration voltages, whereas in particular using 200v provided better results than using 500v or 1000v. Longer bumps usually required to increase the amount number of scans. It is noted that inaccuracies of the bumps can reflect the accuracy of the critical dimension measurements. The inventors found that the added error is less than 1 nano-meter, and that using several bumps and averaging the results for all bumps may improve the precision of the measurement.

Please replace paragraph [0041] with the following amended paragraph:

[0041] Figure 2b illustrates a cross section 230' of another line 210' (not depicted) that has a top section 234, a first traverse section 232 that is positively oriented and a negatively oriented second traverse section 236. Figure 2b also illustrates the convention of positive angles, negative angles and zero angle. ~~The bottom CD of line 210' is D2-D1.~~

Please replace paragraph [0043] with the following amended paragraph:

[0043] The inventors found that using reference elements that are positioned at opposing sides of a measured structural element may be useful in various cases, such as when a single structural element cannot be viewed by electron beams that scan the measured structural element from both of its sides. This can occur when other structural elements are positioned in a very close proximity to the measured structural element, such that as to obscure the reference structural element.

Please replace paragraph [0045] with the following amended paragraph:

[0045] In other embodiments of the invention, multiple reference multiple structural elements are positioned in proximity to a measured structural element, such so as to allow

multiple measurements of the relationship between the measured structural element and the multiple reference structural elements and to allow statistical processing of the multiple relationships to provide better results. Said statistical process processing may average out or otherwise reduce errors and/or inaccuracies associated with a single measurement. This may result from an increment of the overall signal to noise ratio. In some cases, an array of reference structural elements (e.g., similar to bump 250) may be positioned at a first side of a line (e.g., similar to line 210), while in other cases, an array of reference structural elements may be positioned on both sides of a measured structural element. The bottom CD of a line can be responsive to multiple distances measured with respect to these reference structural elements.

Please replace paragraph [0047] with the following amended paragraph:

[0047] Figures 3a – 3c are schematic illustration illustrations of waveforms ~~250 – 252 – 260 – 262~~ that represent a relatively wide positively oriented traverse section, a relatively narrow traverse section and a negative oriented traverse section respectively. As can be seen from these figures, the waveform portion ~~that is~~ associated with steep sidewalls, as well as negative oriented sidewalls is relatively narrow and corresponds to the width of the scanning electron beam.

Please replace paragraph [0048] with the following amended paragraph:

[0048] Figure 4 illustrates a method 400 for determining a location of a traverse section. When a waveform is obtained from scanning a structural element, such as a line, by an electron beam, a portion of a derivative of this waveform may be obtained. For example, a waveform used to provide an estimate of the measure of a traverse section may include 3 points. An intermediate point has a maximal derivative value. The intermediate point is located between an upper point and a lower point, each associated with lower derivative values. The inventors have used an upper point that has a derivative value of about 80% of the maximal derivative value, and a lower point that has a derivative value of about 30% of the maximal derivative value, but other values can be used. A linear estimate of the traverse section is drawn between the upper and lower points. The intersection between said linear estimate and a height threshold provides a location point of the traverse section. The

~~inventor-inventors~~ used a height threshold of 35% of the maximal height of waveform 410, but other values can be used.

Please replace paragraph [0050] with the following amended paragraph:

[0050] Step 470 is followed by step 472 of calculating at least three points – a first point that is characterized by a maximal derivative value, and a lower point and an upper point that are characterized by a predefined derivative values.

Please replace paragraph [0052] with the following amended paragraph:

[0052] According to an embodiment of the invention, the relationship between a reference structural element and a traverse section is actually the relationship between a certain point of the reference structural element and a location point of that traverse section. The certain point of the reference structural element may also be a location point.

Please replace paragraph [0053] with the following amended paragraph:

[0053] It is noted that other points, such as an upper point, an intermediate point, a lower point and/or other points of ~~waveform 410~~ waveforms 260-262 may be used in determining a relationship between a traverse section and a reference structural element.

Please replace paragraph [0054] with the following amended paragraph:

[0054] Figure 5 is a flow chart of method 500 for determining a cross sectional feature of a measured structural element having a sub-micron cross section, the cross section is defined by an intermediate section ~~that is located between a-first and a-second traverse sections~~.

Please replace paragraph [0055] with the following amended paragraph:

[0055] Method 500 measures a feature of a structural element. The measured structural element is a part of a measured object, such as a wafer, die or dice. If appropriate reference structural elements are not positioned at the vicinity of the measured element, they may be added by use of prior art methods for adding and/or removing material, such as Focused Ion Beam (FIB) based methods, ~~Electron-electron~~ beam or even laser based methods. These methods may also require the provision/injection of gas/plasma in a manner known in the

art. A system that implements some of these techniques is the SEMVision G2 FIB of Applied Materials Inc. of Santa Clara, California.

Please replace paragraph [0057] with the following amended paragraph:

[0057] Conveniently, the first relationship is a distance between a certain point of the reference structural element and a first edge of the first traverse section. As ~~illustrates by Figures 2a-2f illustrated by Figure 2a~~, method 500 can be responsive to the relationship between a measured structural element and a single reference structural element, (such as ~~illustrated at Figure 2a~~) but may be responsive to additional relationships[[,]] between the measured structural element ~~to and~~ multiple reference structural elements (such as ~~illustrated in Figures 2e or 2f~~).

Please replace paragraph [0059] with the following amended paragraph:

[0059] It is noted that the invention can be adapted to handle other shaped and/or sized structural elements. The height of the reference structural element may be taken into account, for example by using elementary geometrical equations, ~~for compensating to compensate~~ for a height difference between the bottom of the measured structural element and the reference structural element.

Please replace paragraph [0062] with the following amended paragraph:

[0062] According to another embodiment of the invention, if one or more additional relationships were determined during steps 520 and 530, then the determination of step 540 is further responsive to at least one of the additional relationships.

Please replace paragraph [0063] with the following amended paragraph:

[0063] It is noted that during a tilt stage the electron beam may be tilted in relation to an imaginary plane that is perpendicular to the measured object. The tilt angle can be positive or negative. According to an embodiment of the invention, during the first tilt state the electron beam is tilted at a positive angle, while during the second tilt state the electron beam is tilted at a negative angle.

Please replace paragraph [0064] with the following amended paragraph:

[0064] According to another embodiment of the invention, during the first tilt state the electron beam is tilted at a negative angle, while during the second tilt state the electron beam is tilted at a positive angle.

Please replace paragraph [0065] with the following amended paragraph:

[0065] According to an embodiment of the invention, during the first or second tilt state the electron beam is tilted at substantially zero degrees.

Please replace paragraph [0067] with the following amended paragraph:

[0067] Figure 6 is a flow chart of method 600 for determining a cross sectional feature of a measured structural element having a sub-micron cross section, the cross section is defined by an intermediate section ~~that~~ is located between a first and a second traverse sections.

Please replace paragraph [0069] with the following amended paragraph:

[0069] Step 620 is followed by query step 625 of determining whether to perform an additional scanning step. If the answer is yes, method 600 proceeds to step 630, else the method proceeds to step 640.

Please replace paragraph [0070] with the following amended paragraph:

[0070] The determination of step 625 may be responsive to various parameters, such as, but not limited to, top, bottom, maximal and/or minimal width of the measured structural element, estimated or measured orientation of a traverse section and/or estimated or measured width of a traverse section. The estimation can involve processing of detection signals[[,]] and comparison with detection signals originating from other structural elements. The comparison may involve die to die comparison, die to data base comparison and the like.

Please replace paragraph [0071] with the following amended paragraph:

[0071] An additional scanning step may be required if one traverse section (or both) is (are) suspected to be either steep (for example above a steepness threshold) or to be negatively oriented. This orientation may be estimated from waveforms acquired during the detection of signals resulting from the scan of the measured structural element. Steep traverse sections, as well as negative oriented traverse sections, are associated with certain waveforms. The inventors found that such a traverse section is sections are suspected if the width of it the waveform substantially equals the width of the electron beam. The inventors also found the that a comparison of waveforms to previously recorded waveforms of known elements may also be used.

Please replace paragraph [0074] with the following amended paragraph:

[0074] According to another embodiment of the invention, if one or more additional relationships were determined during steps 620 and 630, then the determination of step 640 is further responsive to at least one of the additional relationships.

Please replace paragraph [0075] with the following amended paragraph:

[0075] Figure 7 is a flow chart of method 700 for determining a cross sectional feature of a measured structural element having a sub-micron cross section, the cross section is defined by an intermediate section that is located between a first and a second traverse sections.

Please replace paragraph [0079] with the following amended paragraph:

[0079] According to an embodiment of the invention, the measured structural element is positioned between the first and second reference structural elements.

Please replace paragraph [0080] with the following amended paragraph:

[0080] The relationship (usually distance and optionally height difference) between the first and second reference element feature elements must be measured/ estimated. Inaccuracies in this measurement may effect-affect the measurement of the cross sectional feature.

Please replace paragraph [0081] with the following amended paragraph:

[0081] Step 700 may include a preliminary step of either estimating or receiving this reference relationship, but it may also include a step 710 of measuring it. The measurement may take place in locations other than the location in which the measured element is being measured, so that various contamination/~~carbonization~~. Shrinkage, carbonization or shrinkage effects will not effect-affect the measurement of the measured structural element.

Please replace paragraph [0082] with the following amended paragraph:

[0082] Step 710 may include one or more ~~sean~~ scans of an area that includes the first and second points of the first and second reference elements and the measured structural element. Step 710 may also include preventing the electron beam to illuminate from illuminating the measured structural element. This can be implemented by blanking the beam while it is supposed to illuminate the measured structural element.

Please replace paragraph [0083] with the following amended paragraph:

[0083] Figure 8 is a flow chart of method 800 for determining a cross sectional feature of a measured structural element having a sub-micron cross section, the cross section is defined by an intermediate section ~~that is~~ located between a first and a second traverse section.

Please replace paragraph [0085] with the following amended paragraph:

[0085] Step 820 is followed by query step 825 for determining whether an additional scanning step is required for determining an additional relationship between the reference structural element and the at least one traverse section. If the answer is positive, method 820 proceeds to step 830, else it proceeds to step 840. This determination may be responsive to an estimated width of a traverse section, to an estimated orientation of a traverse section, to an estimated cross sectional feature of the measured structural element, and the like.

Please replace paragraph [0088] with the following amended paragraph:

[0088] Figure 9 is a flow chart of method 900 for determining a cross sectional feature of a measured structural element having a sub-micron cross section, the cross section is-defined by an intermediate section ~~that is~~ located between a first and a second traverse sections.

Please replace paragraph [0090] with the following amended paragraph:

[0090] Step 920 is followed by step 930 of scanning, at a second tilt state, second portion portions of the set of reference structural elements and at least the second traverse section of the measured structural element, to determine a second set of relationships between reference structural elements of the set of reference structural elements and the second traverse section.

Please replace paragraph [0093] with the following amended paragraph:

[0093] Is noted that the intermediate section, which may be a top section in the case of an elevated structural element, may be determined from each of the scanning steps. It is further noted that given the first and second traverse section cross sectional features the cross section of the structural element as well as any feature (such as, but not limited to, top CD, bottom CD, maximal CD) of said cross section can be determined. A typical cross sectional feature is the horizontal projection of a traverse section. In cases where the tilt angle is relatively small, it is assumed that the tilt angle is approximately equal to the Tangents tangent of this angle.

Please replace paragraph [0094] with the following amended paragraph:

[0094] It is noted that some of the measurements may be repeated, and that additional tilted scans of the structural element (with the same and/or differing tilt angles) may be performed for various reasons, such as averaging out statistical noise, and the like. Accordingly, methods 400 and 500 may include multiple measurements of one or more cross sectional features, even if the height of the structural elements ~~in were~~ known or estimated and even if a certain cross sectional feature ~~was were~~ measured.

Please replace paragraph [0095] with the following amended paragraph:

[0095] The present invention can be practiced by employing conventional tools, methodology and components. Accordingly, the details of such tools, component and methodology are not set forth herein in detail. In the previous descriptions, numerous specific details are set forth, such as shapes of cross sections of typical lines, ~~amount number~~ of deflection units, etc., in order to provide a thorough understanding of the present

invention. However, it should be recognized that the present invention might be practiced without resorting to the details specifically set forth.